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OFFICE NOTE 157

On the Performance of the NMC 9-Layer Global Prediction Model Without the Material-Surface Tropopause

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This is an unreviewed manuscript, primarily intended for informal exchange of information among NMC staff members.

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I. Introduction

The use of baroclinic primitive equation prediction models in numerical weather prediction and general circulation studies began nearly 20 years ago and has become quite widespread. Most of the models have used pressure normalized by surface pressure as the vertical coordinate (Phillips, 1957). In this formulation, the lowest coordinate surface (pressure at the model terrain level) and the uppermost coordinate surface (usually corresponding to p=0) are material surfaces: i.e., no exchange of substance is permitted across the surface.

At NMC, the first primitive-equation prediction model was introduced into daily operations in 1966 (Shuman and Hovermale, 1968). The vertical coordinate of this model used a variation of normalized pressure, in which a separate material surface was added in the vicinity of the tropopause. This was a pragmatic attempt to improve the resolution of the thermal structure in an area of large gradients without the expense of additional layers. It is unique to NMC; no other modeling group has adopted this technique. Two subsequent NMC models, the LFM and the 9-layer global model, inherited this feature.

Whatever benefits might accrue with respect to resolution, the material-surface tropopause has always had its troublesome aspects. Its initial specification is difficult, and mistakes can be fatal. If the analyzed tropopause is placed at too low a pressure, for example, the model stratosphere may encounter numerical difficulties in the subsequent forecast. This is an infrequent occurrence, largely because of stringent controls placed on the location of the tropopause. More common is the disturbance of the mass-motion balance in the prediction model due to the vertical redistribution of mass; the disturbance manifests itself as gravitational noise. This is especially troublesome in data assimilation, where the prediction model is updated frequently.

In view of this, and noting that all of the next-generation models currently being developed at NMC do not make use of the material-surface tropopause, an experiment was recently conducted to examine the impact of withdrawing the tropopause. This note describes the experiment and its results.

II. The experiment

The NMC 9-layer global model (Stackpole, et al., 1974) was used in the experiment. Modifications were made by J. Stackpole to replace the 6-layer troposphere, 3-layer stratosphere vertical arrangement with a single sigma-domain defined by

$$\sigma = \frac{P - 50}{P_{sfc} - 50} .$$

The modified vertical structure thus has nine layers of equal pressure-thickness. If the surface pressure is 1000 mb, each layer is approximately 105 mb thick. On the average, this represents an increase in resolution in the troposphere but a decrease in the stratosphere.

The experiment consisted of two parallel analysis/forecast cycles identical in every respect except that the control cycle used the material-surface tropopause formulation, while the experimental cycle did not. Both began from the same initial state--an operational 12-hour forecast valid at 00 GMT on 18 August 1975--but thereafter cycled independently of each other. Both used the global spectral objective analysis system to update the 5^{o} version of the prediction model each 6 hours, through 5 days.

Evaluation of the experiment consisted of verifying the 6-hour forecasts valid at midnight and noon Greenwich time against radiosonde observations at 80 North American and European locations, and calculating maps of the differences between the two cycles.

III. Results

Figure 1 presents the results of the verifications. Shown are root-mean-square (RMS) height, temperature, and vector wind errors as functions of pressure, averaged over the 10 cases. Generally, there is not much difference in the scores below tropopause levels. Above 300 mb, however, height and temperature errors are very large.

This is primarily a result of an excessive bias in temperature error in the upper levels: on the average, the temperatures at 100 mb are too warm. Figure 2 illustrates this, displaying the difference in the 100 mb temperature forecasts valid at 00 GMT 23 August 1975. The sense is such that positive values mean warmer temperatures for the no-tropopause run. It will be noted that negative differences are small, and confined to generally poleward of 60N; the largest negative is around -2C. On the other hand, the bias is positive nearly everywhere equatorward of 60N, and increases in magnitude toward the equator.

Figures 3 and 4 present temperature profiles of a gridpoint (40N,95W) near Topeka, Kansas. Shown on each is the profile from the experiment (crosses), that from the control (triangles), and the solid line gives the Topeka radiosonde profile for 00 GMT 23 August 1975, repeated on both figures. The 6-hour forecast profiles valid at that time are given in Figure 3. It is clear that the control profile depicts the essentials of the thermal structure but the experiment has completely failed to do so, missing entirely the inversion above 100 mb.

Some understanding of the reason for this may be obtained from Figure 4. On the left and right sides of the diagram may be found the approximate distribution of layers at this gridpoint, from the control and experiment, respectively. The tropopause is near 140 mb. In the case of the control, there are three layers, each approximately 30 mb thick, above the tropopause. The uppermost tropospheric layer is about 140 mb thick. In the control case, the procedure used to interpolate from these layers in the model's coordinate to the constant pressure levels makes use of the location of the tropopause. The temperature profile is extrapolated (linearly with logarithm of pressure) upward from the uppermost two tropospheric layers to the tropopause. Likewise, downward extrapolation is used in the stratosphere; but in no case is interpolation permitted <u>across</u> the tropopause.

On the other hand, according to the right side of Figure 4, the experimental configuration has only one layer to represent the stratosphere, centered near 100 mb. The uppermost layer is centered near 100 mb. The next lower layer is centered near 210 mb. Mandatory-level temperatures between these two layers are interpolated linearly with logarithms of pressure, without regard to the tropopause. The result is a fictitiously warm profile near the tropopause. Above the midpoint of the single stratospheric layer, the temperatures are extrapolations from below. They consequently reflect the usual tropospheric lapse of temperature, and are therefore too cold.

Figure 4 also shows that with regard to service as a "first guess" for the objective analysis, the lack of resolution in the stratosphere is not so important in data-dense regions; both control and experiment reflect the Topeka radiosonde almost identically. But in data-sparse areas, the effects may be cumulative and detrimental. Figure 5 shows the difference in wind speed at 100 mb at the end of the experiment. The differences are small over the data-dense areas of North America and Europe. Over the oceans, however, the differences tend to be large and negative, indicating lower wind speeds in the experiment.

IV. Conclusions

This experiment has demonstrated that the removal of the material-surface tropopause in the 9-layer global model has a serious and detrimental impact in the stratosphere and upper troposphere, and no discernible benefit in the lower troposphere. It is clear that the tropopause does effectively enhance the vertical resolution of the NMC models; and its removal cannot be justified without some compensatory adjustments. Such adjustments might be

- unequally-spaced layers, with greater resolution near the tropopause;
- improved vertical interpolation methods;
- increased vertical resolution;
- some combination of the above.

References

Phillips, N., 1957: "A coordinate system having some special advantages for numerical forecasting." J. Meteor., 14, 184-185.

Shuman, F., and J. Hovermale, 1968: "An operational six-layer primitive equation model." J. Appl. Meteor., 2, 525-547.

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Acknowledgments

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FPI-MI—10 X 10 TO 1 INCH
5TH LINE ACCENTED, 10TH HEAVY

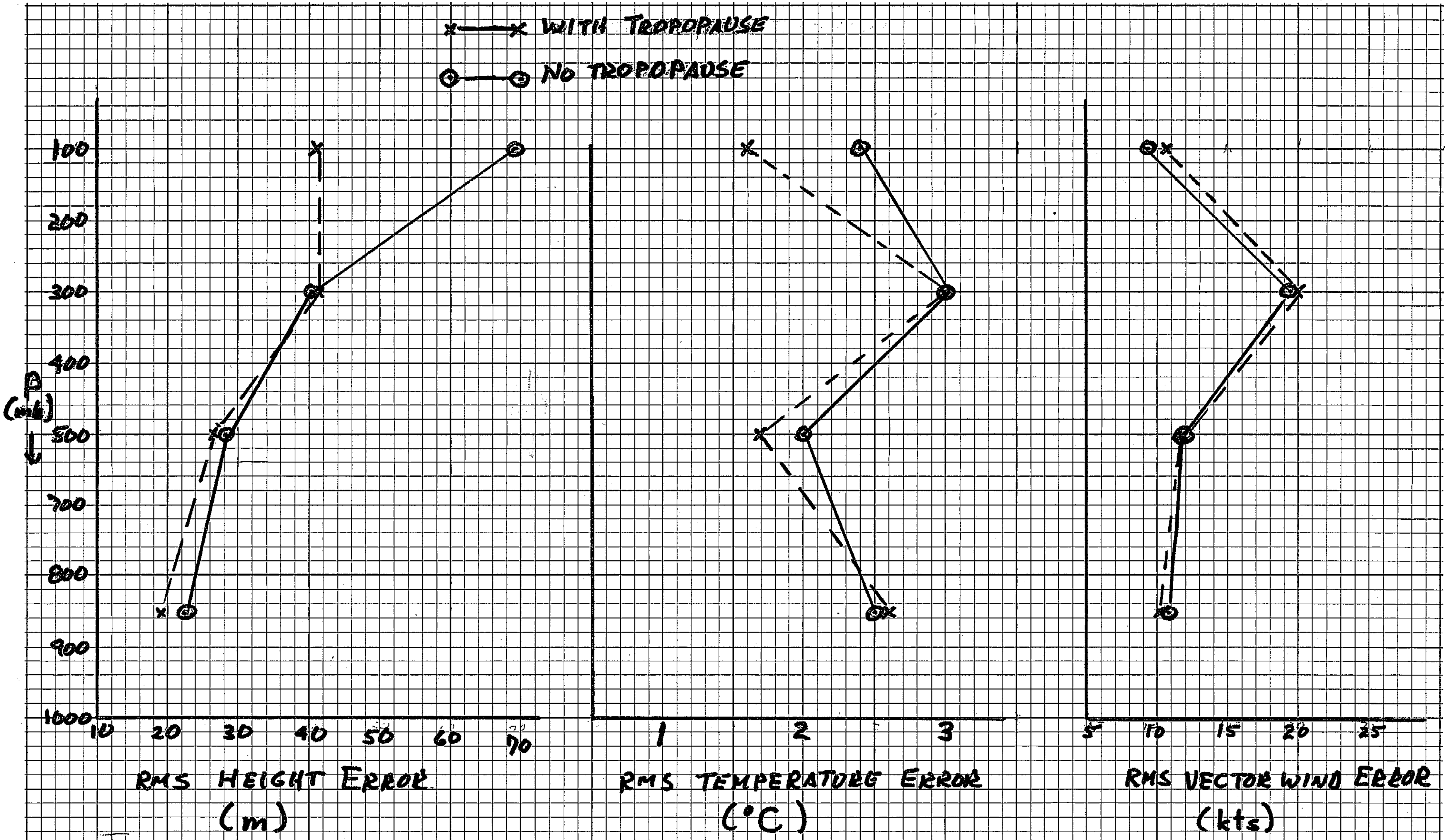

Figure 1. RMS height, temperature, and vector wind errors in 6h forecasts valid at 0000 GMT and 1200 GMT as functions of pressure. Verifications are against 80 Northern Hemisphere radiosonde stations. The numbers plotted are averages over 10 cases. The control is represented by the dashed line, and the experiment by the solid line.

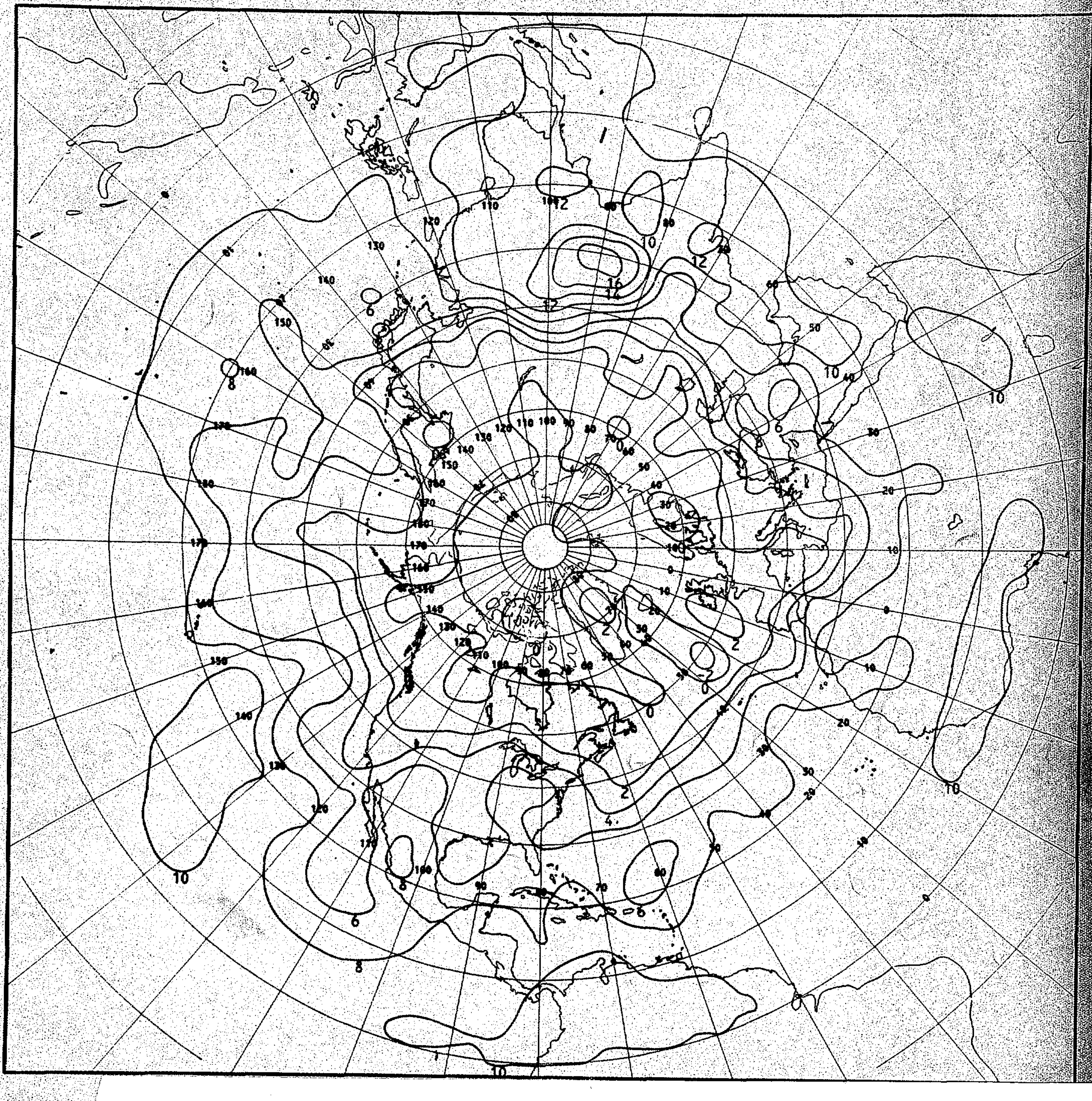

Figure 2. 100 mb temperature difference (experiment-control) for 0000 GMT 23 August 1975. Contour interval is 2C.

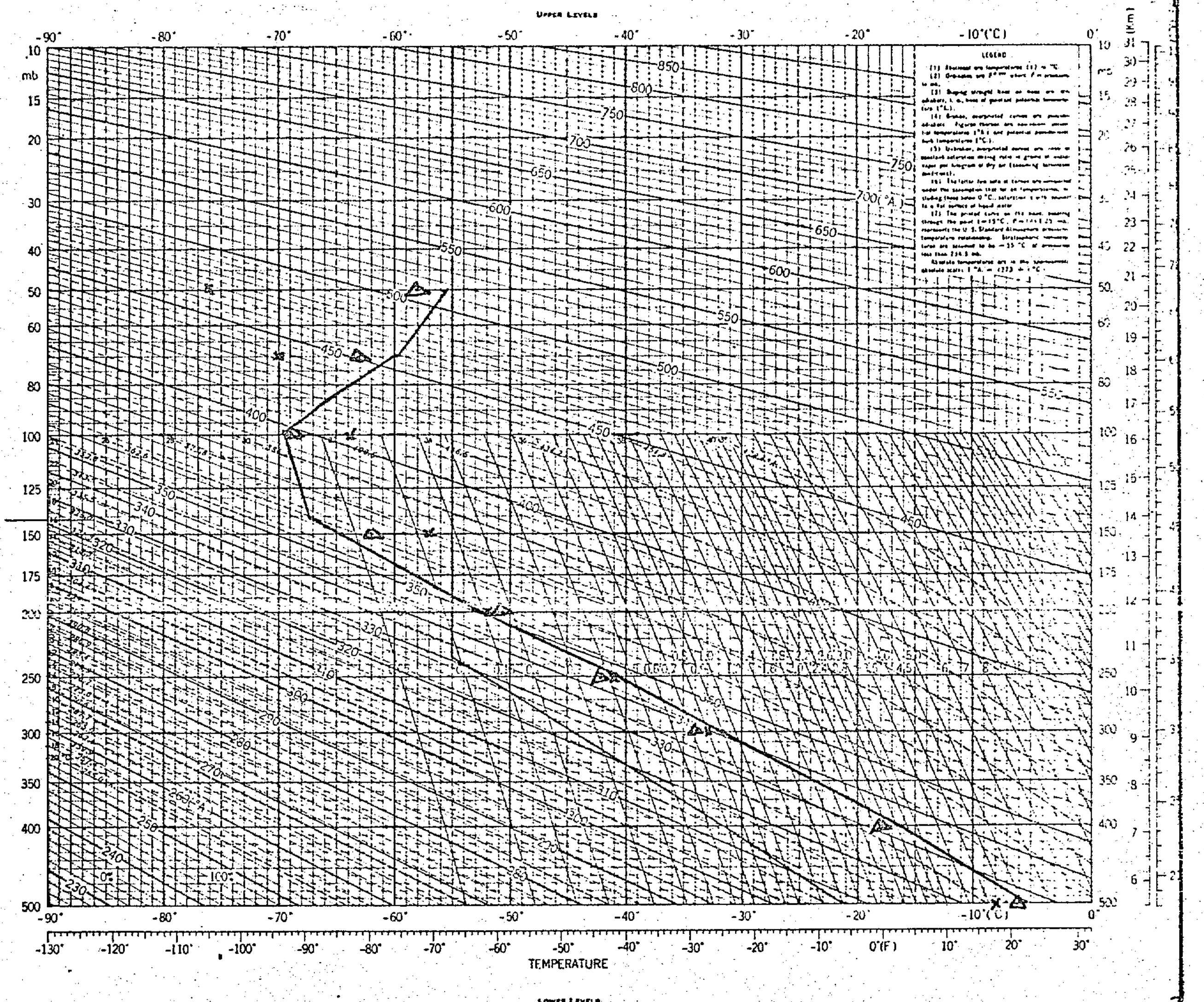

Figure 3: Forecast temperature profiles from the control (triangles) and the experiment (crosses) for Topeka, Kansas, valid at 0000 GMT 23 August 1975. Solid line is the Topeka radiosonde profile.

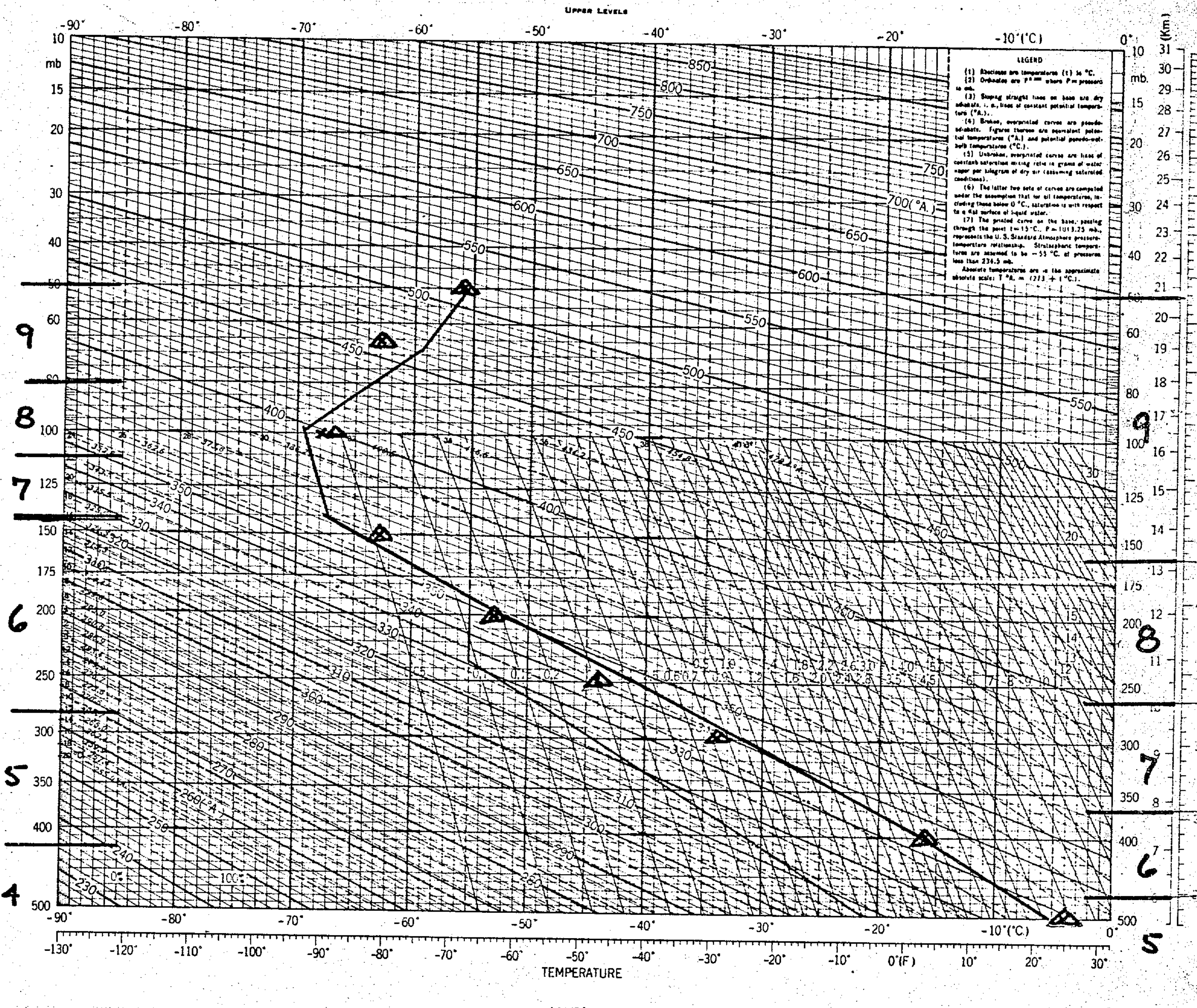

Figure 4: Analyzed temperature profiles from the control (triangles) and the experiment (crosses) for Topeka, Kansas, at 0000 GMT 23 August 1975. Solid line is the Topeka radiosonde profile. Notations on the left side of the diagram indicate the approximate stratification of the model in the control run; those on the right are for the experiment.

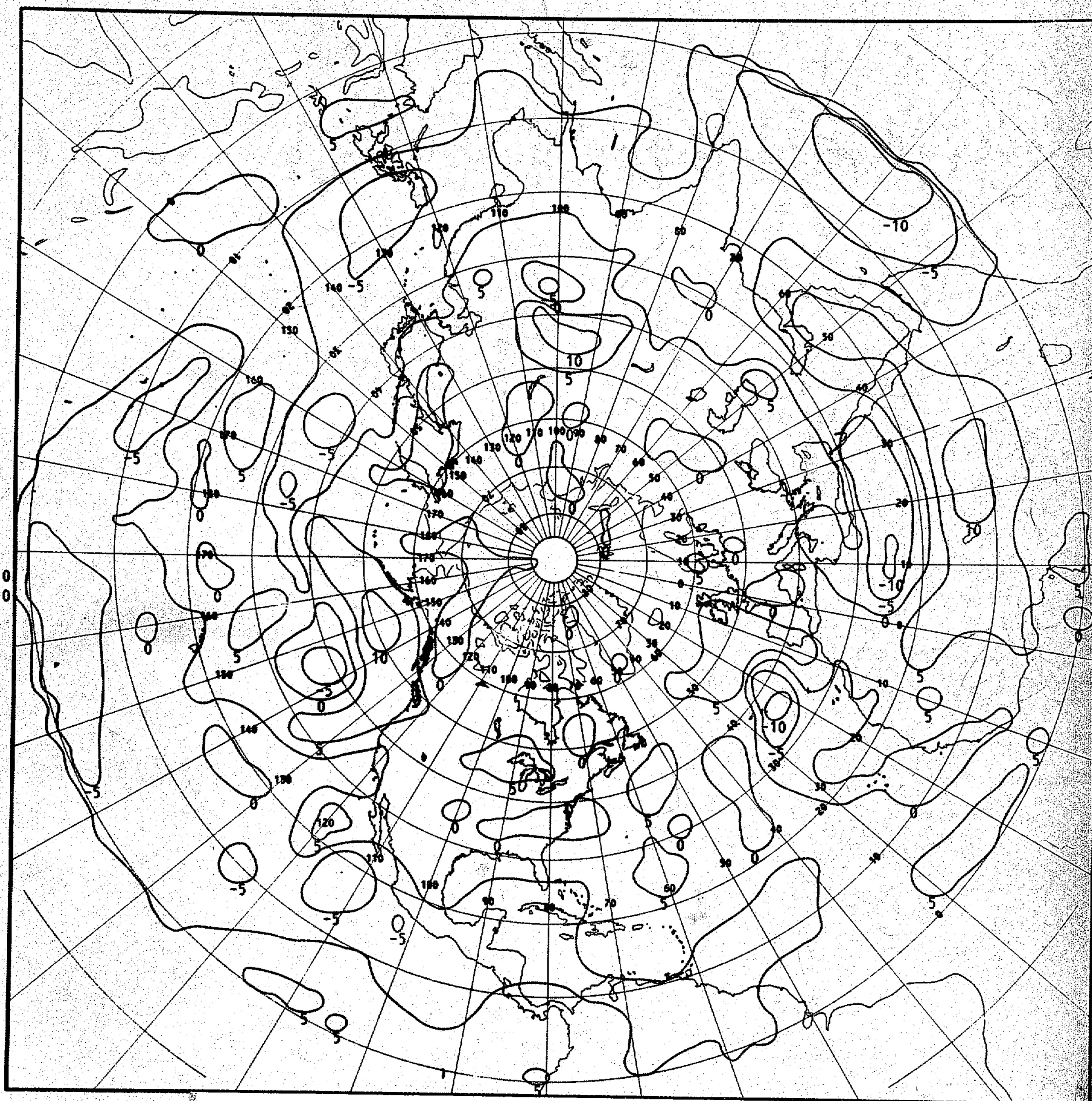

Figure 5: 100 mb wind speed difference (experiment-control) for 0000 GMT 23 August 1975.
Contour interval is 5 m sec^{-1}.